DISPERSION OF FERN SPORES INTO AND WITHIN A FOREST[1]

GILBERT S. RAYNOR, EUGENE C. OGDEN AND JANET V. HAYES

Experiments were conducted at Brookhaven National Laboratory over a nine-year period to study the spread by atmospheric dispersion of small particles released within and upwind of a forest. Most particles utilized were pollens and spores selected for a range of sizes. One hundred nineteen releases were made in forty-two separate experiments. Ragweed (*Ambrosia*) pollen was studied most extensively and may be considered a reference particle to which other tracers can be compared. Spores of ferns (*Osmunda* and *Dryopteris*) were released in four tests and, in each case, ragweed pollen was released simultaneously from the same location. This paper describes the dispersion of these fern spores and compares it to the dispersion of ragweed pollen. The forest dispersion studies and their results have been reported previously but without detailed consideration of the fern spore releases (Raynor, *et al.*, 1972, 1974a, 1974b, 1975).

SITE

Experiments were conducted in a forest composed largely of Red Pine (*Pinus resinosa*) with smaller amounts of White Pine (*P. strobus*), Pitch Pine (*P. rigida*) and several deciduous species. Average tree height increased from about 10.5 to 13.0 m during the experimental years. The stand is rather dense with 1474 trees per hectare. The canopy is mostly closed but numerous small openings are

[1]This research was carried out under the auspices of the New York State Museum and Science Service and the U. S. Atomic Energy Commission (now the U. S. Energy Research and Development Administration) and was partially supported by Research Grant No. R-800677 from the Division of Meteorology, U. S. Environmental Protection Agency.

present. The forest has a straight edge in an east-west direction with an open field to the south. Except at the edge where dense foliage extends to the surface, little living foliage is present below 2 to 4 m. Sparse undergrowth is present only in a few clearings. More detailed descriptions of the site with illustrations were given earlier (Raynor, 1971; Raynor *et al.*, 1972).

EQUIPMENT AND METHODS

The sampling network was composed of 119 rotoslide samplers (Ogden and Raynor, 1967) mounted at heights from 0.5 to 21.0 m on towers and other supports along seven rows, 10 m apart, extending from just outside the forest edge to 100 m into the forest at right angles to the edge. These samplers rotate at about 1500 revolutions per minute and collect particles by impaction on the edges of two microscope slides. The edges are coated with silicone grease to insure retention of impacted particles. Deposition to the ground was measured by two greased microscope slides at each of the 57 sampling locations.

Meteorological conditions at the experimental site were measured by 25 sensitive cup anemometers mounted in and near the forest at heights from 1.75 to 21.0 m and by 10 aspirated temperature sensors mounted at selected heights in the forest and the field. Other measurements were taken at a nearby meteorological installation.

The micrometeorology of the forest was described earlier (Raynor, 1971) but is summarized briefly here. With a long fetch through the forest, wind speeds below the canopy are very light compared to those in the open and vary little from near the ground to mid-canopy where an increase takes place. When winds penetrate the edge from the field, speeds are greater in the trunk space than in the canopy for a distance of about 60 m. When unstable lapse rates are present outside the forest, a temperature inversion or an isothermal layer is typical below the canopy. The vertical component of turbulence is more pronounced and the lateral component less so than in the open.

Particles used as tracers were previously purchased or collected, suspended in a liquid and sprayed out through compressed-air-operated atomizing nozzles (Raynor and Smith, 1964). Pollens were prestained with selected colors (Raynor, *et al.*, 1966) to facilitate identification and counting but the darker spores did not absorb the stains used and were identified after collection by size, shape and surface characteristics. Ragweed pollen is spheroidal, rough and about 20 μm in diameter. *Osmunda* spores are also spheroidal but smooth and average about 54 μm in diameter. *Dryopteris* spores are ovoidal, slightly rough and average about 33 $\times$ 45 μm.

In preparation for an experiment, the selected quantity of particles was weighed on a laboratory balance, mixed in a liquid and both stirred and agitated ultrasonically to separate clumps. When pollens were used, the dye was added to the liquid at this stage. When well mixed, the suspension was placed in the dispensing apparatus at the selected release point. Mixing continued during the release period which usually lasted from 20 to 40 minutes. Slides were placed in the samplers and at the deposition sites shortly before emission. Rotoslide samplers were started before release began and operated until after the spray terminated. In most tests, releases of the same particle type were made from three locations simultaneously but, in others, several particle types were emitted from the same location. After each test, slides were collected and stored for later analysis. Each type of particle or each color of pollen used was counted separately on each slide by use of a microscope.

The count data were normalized by the volume of air sampled and by the sampler efficiency to give concentrations in particles/m^3 of air sampled. Deposition data were expressed as particles/m^2 of ground surface. No measurement was obtained of particles which impacted or deposited on the vegetation. Since the number of particles/gram had previously been determined for each species, the number of particles released in each test was calculated. Therefore, all concentration and deposition data were further normalized by the output rate so that these parameters were expressed as percentages of the total output. This allowed direct comparison of results between tests since amounts released varied from one test or one particle type to another. The data were then analyzed in various ways to determine the rate and character of dispersion and the rate of particle loss from the air.

More complete descriptions of the equipment and methods used were given earlier (Raynor, *et al.,* 1966, 1972, 1974a, 1974b, 1975).

RESULTS

Since only four tests were made using fern spores, these are described separately and results compared directly to results from simultaneous ragweed pollen releases. Since the fern spore data were too few for certain analyses performed on the more complete pollen data, only selected analyses are discussed here. However, these are adequate to characterize the results found and to indicate the behavior of fern spores under the conditions of the experiments.

In test 30, *Osmunda* spores and ragweed pollen were released from a height of 1.75 m at a point in the field 15 m upwind of the forest edge. The normalized concentration patterns at the 1.75 m height are shown in Figure 1a and are qualitatively similar. Mean wind speed was 2.3 m/sec. at the release point, adequate for good penetration into the forest edge. As found for upwind releases in general (Raynor, *et al.,* 1974b) the plumes widen greatly before the edge is reached due to increased turbulence in this region, but additional lateral spread within the forest is small. The fern spore pattern is more irregular, probably due to two factors: 1) the smaller number of particles emitted with consequent smaller and less reliable counts and 2) more rapid removal by impaction and deposition at

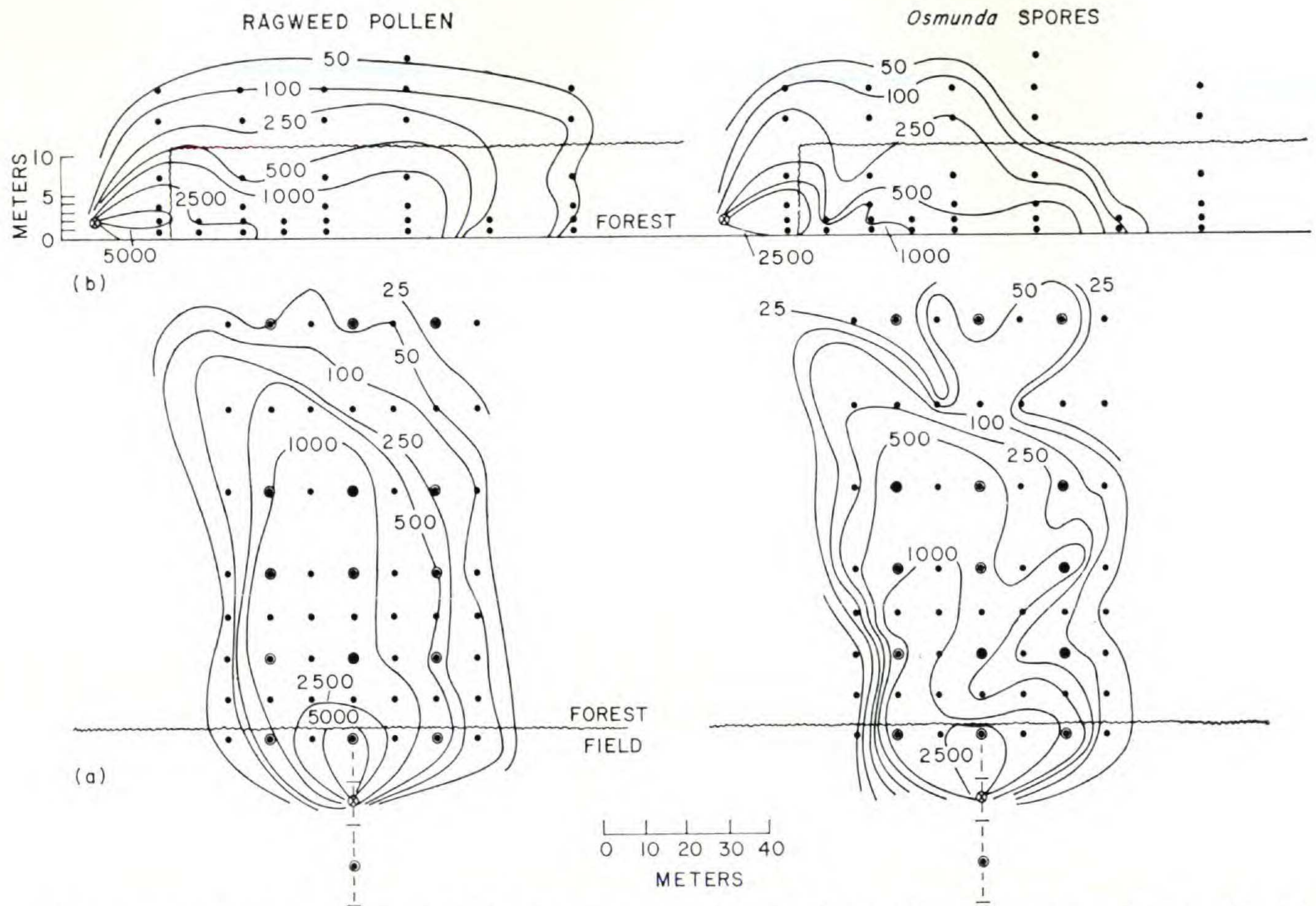

Figure 1. Concentration isopleth patterns resulting from simultaneous releases of ragweed pollen and *Osmunda* spores at a height of 1.75 m, 15 m upwind of the forest edge. Test 30. (a) horizontal plane at a height of 1.75 m. (b) downwind-vertical plane along the grid centerline.

locations in the forest where local foliage distribution and wind flow patterns favored these processes. For both particles, maximum concentrations are found to the left of the centerline of the sampling grid, apparently due to channelling of the air by variations in foliage density.

Figure 1b shows vertical cross sections along the downwind centerline of the sampling grid. Although some of both particles were carried up over the forest at the edge, the concentration isopleths of the *Osmunda* spores slope down at 60 m in the forest whereas those of the ragweed pollen remain nearly horizontal to the most distant sampling location. This effect is due to more rapid settling and removal of the larger fern spores.

In test 40, *Dryopteris* spores and ragweed pollen were released simultaneously from a height of 1.75 m at a location 95 m in the forest with the wind blowing through the forest towards the field. As shown in Figure 2a, concentrations of *Dryopteris* spores decreased much more rapidly with distance than concentrations of ragweed pollen, again due to the greater loss of the larger fern spores. Mean wind speed was only 0.4 m/sec. at the release point so the clouds of particles moved slowly through the forest with ample time for settling to the ground and to the foliage.

Figure 2b shows the downwind cross section along the grid centerline. The lesser height reached by comparable concentrations of fern spores and the more rapid decrease with distance are evident.

In test 26, *Osmunda* spores and ragweed pollen were emitted together from a height of 1.75 m, 100 m in the forest. Wind speed was again 0.4 m/sec. at the release point but somewhat less above the forest than in test 40. Concentrations of *Osmunda* spores (Figure 3) decreased very rapidly with distance and became negligible in about 40 m while concentrations of ragweed pollen remained appreciable to the forest edge at 100 m. The vertical patterns are not shown since the fern spores remained low within the forest.

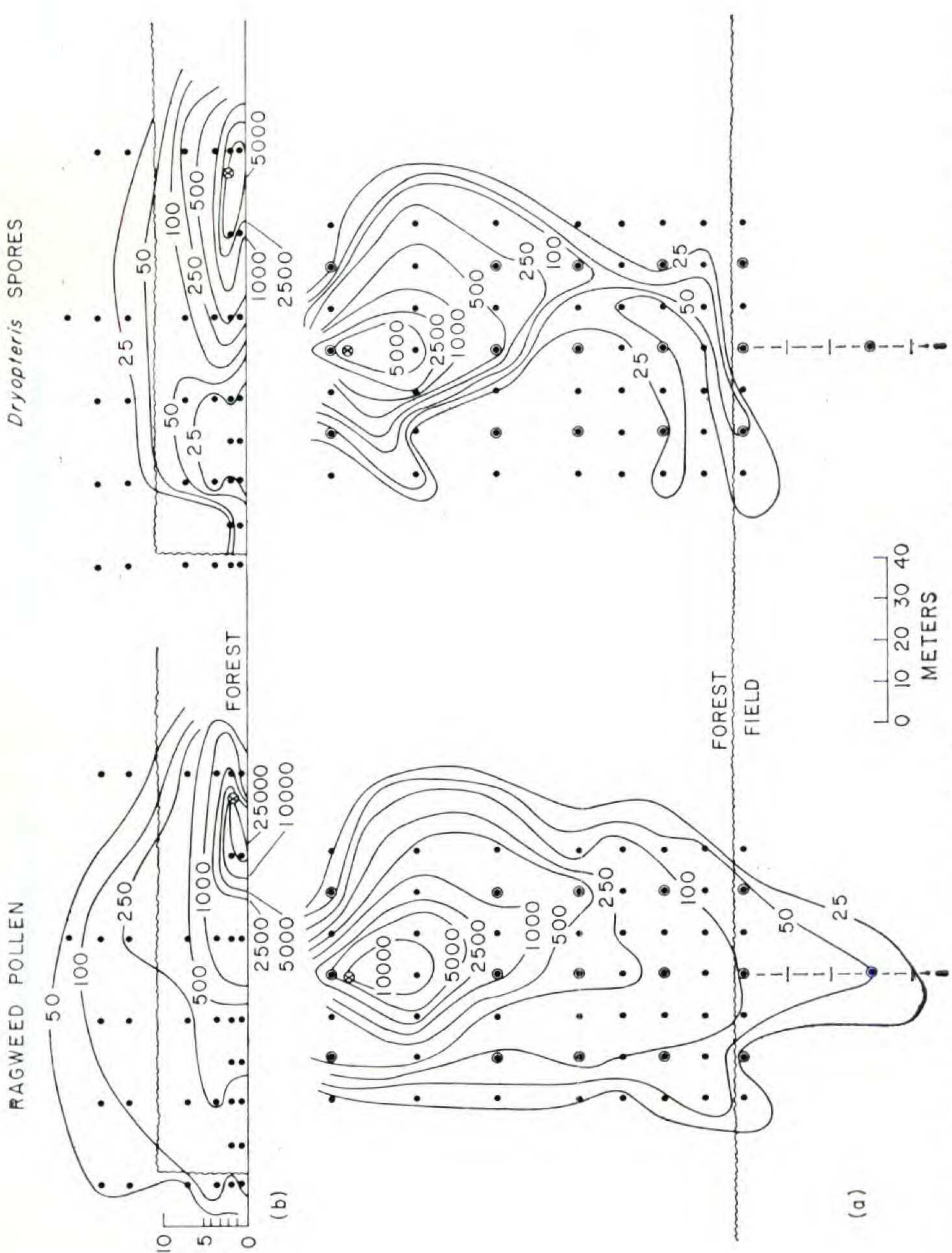

Figure 2. Concentration isopleth patterns resulting from simultaneous releases of ragweed pollen and *Dryopteris* spores at a height of 1.75 m, 95 m in the forest. Test 40. (a) horizontal plane at a height of 1.75 m. (b) downwind-vertical plane along the grid centerline.

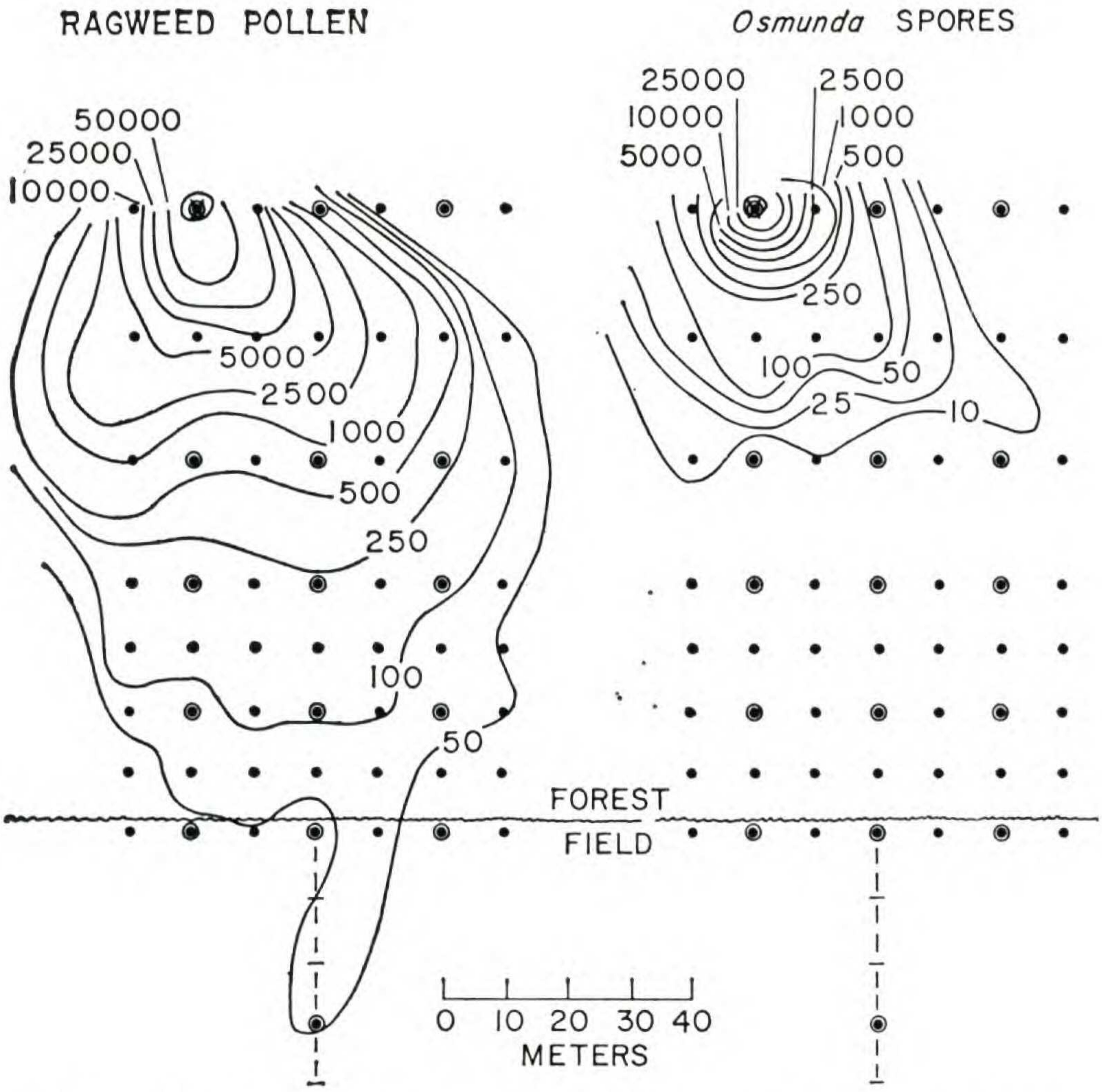

Figure 3. Concentration isopleth patterns in the horizontal plane at a height of 1.75 m resulting from simultaneous releases of ragweed pollen and *Osmunda* spores at a height of 1.75 m, 100 m in the forest. Test 26.

Nearly identical results were obtained in test 32 when the same particles were released at the same height 95 m in the forest. Wind speed at the release point was only about 0.1 m/sec. and that above the forest at a height of 14 m only 1.4 m/sec. Thus, wind directions were variable and many of the particles were transported to the northwest and out of the sampling grid instead of to the south as had been expected (Figure 4). However, it is obvious that the *Osmunda* spores were lost from the air in a very short distance in contrast to the ragweed pollen.

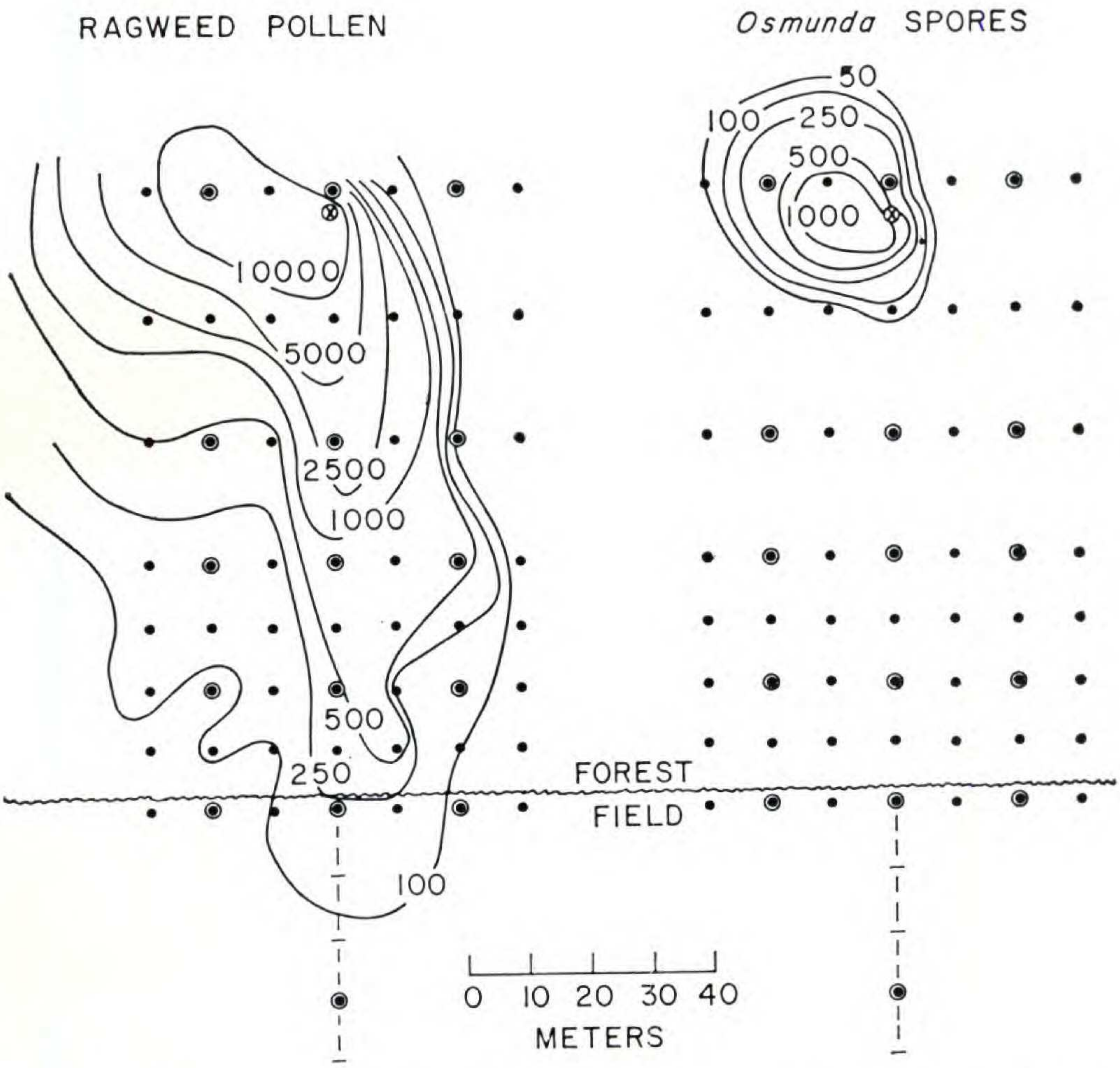

Figure 4. Concentration isopleth patterns in the horizontal plane at a height of 1.75 m resulting from simultaneous releases of ragweed pollen and *Osmunda* spores at a height of 1.75 m, 95 m in the forest. Test 32.

Centerline concentrations at the 1.75 m level were normalized to 100% at the edge of the forest and plotted as a function of distance within the forest (Figure 5). Except for greater irregularity in the *Osmunda* curve (B) rate of loss was not significantly different than for ragweed pollen (A).

The concentration data were then integrated in all three coordinate directions to give the mass flux or the total number of particles remaining airborne at each distance. These data are also plotted relative to the values at the

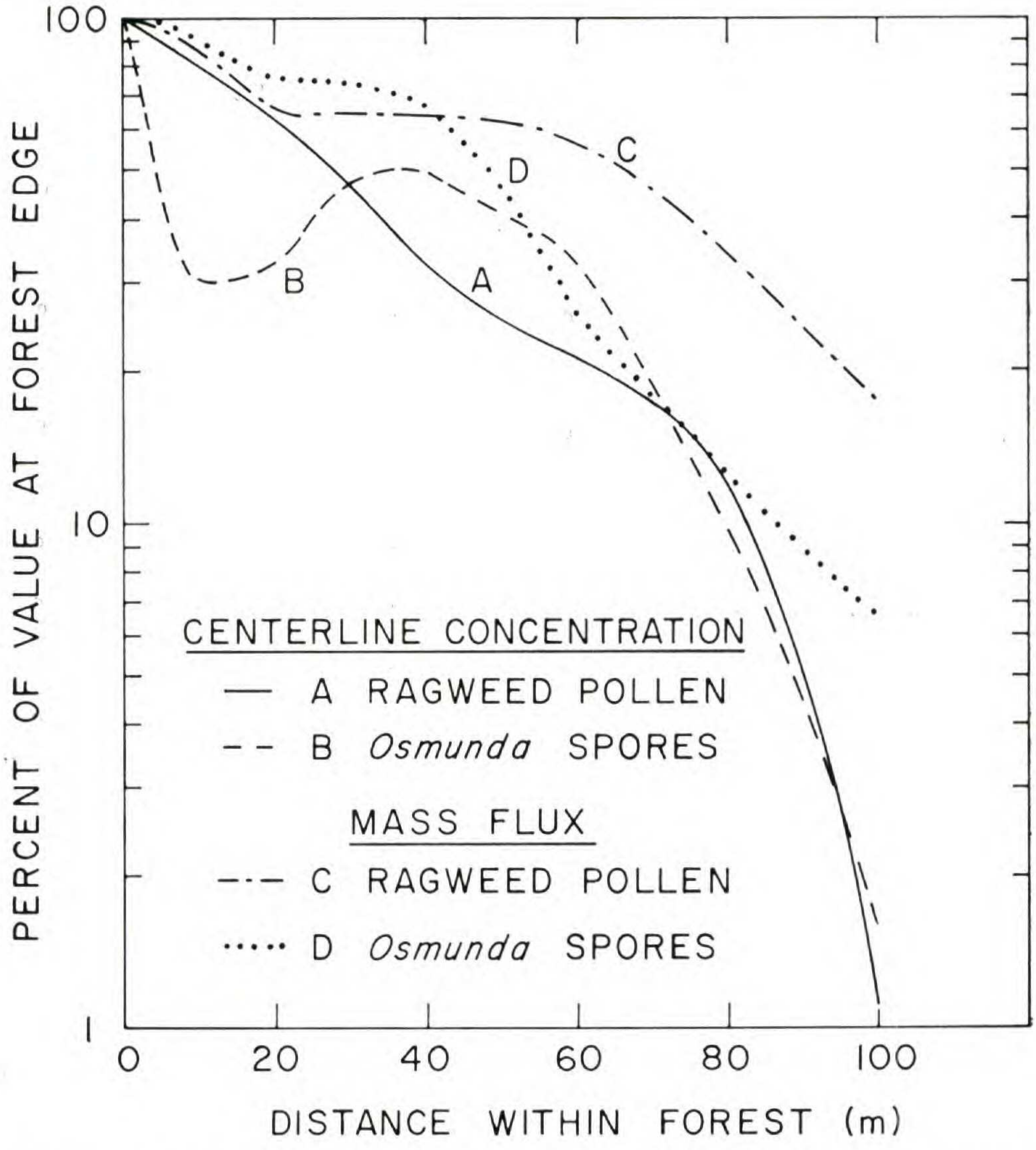

Figure 5. Normalized centerline concentrations and mass flux as a function of distance within the forest for simultaneous releases of ragweed pollen and *Osmunda* spores upwind of the forest edge. Test 30.

edge of the forest in Figure 5. Here, it is seen that the *Osmunda* spores (D) are lost appreciably faster than the pollen grains (C) so that at 100 m, nearly three times as many pollen grains remain airborne.

Deposition to the ground of the two particles is compared in a similar way in Figure 6. Since centerline deposition was typically irregular, deposition integrated in the crosswind direction across the width of the deposition

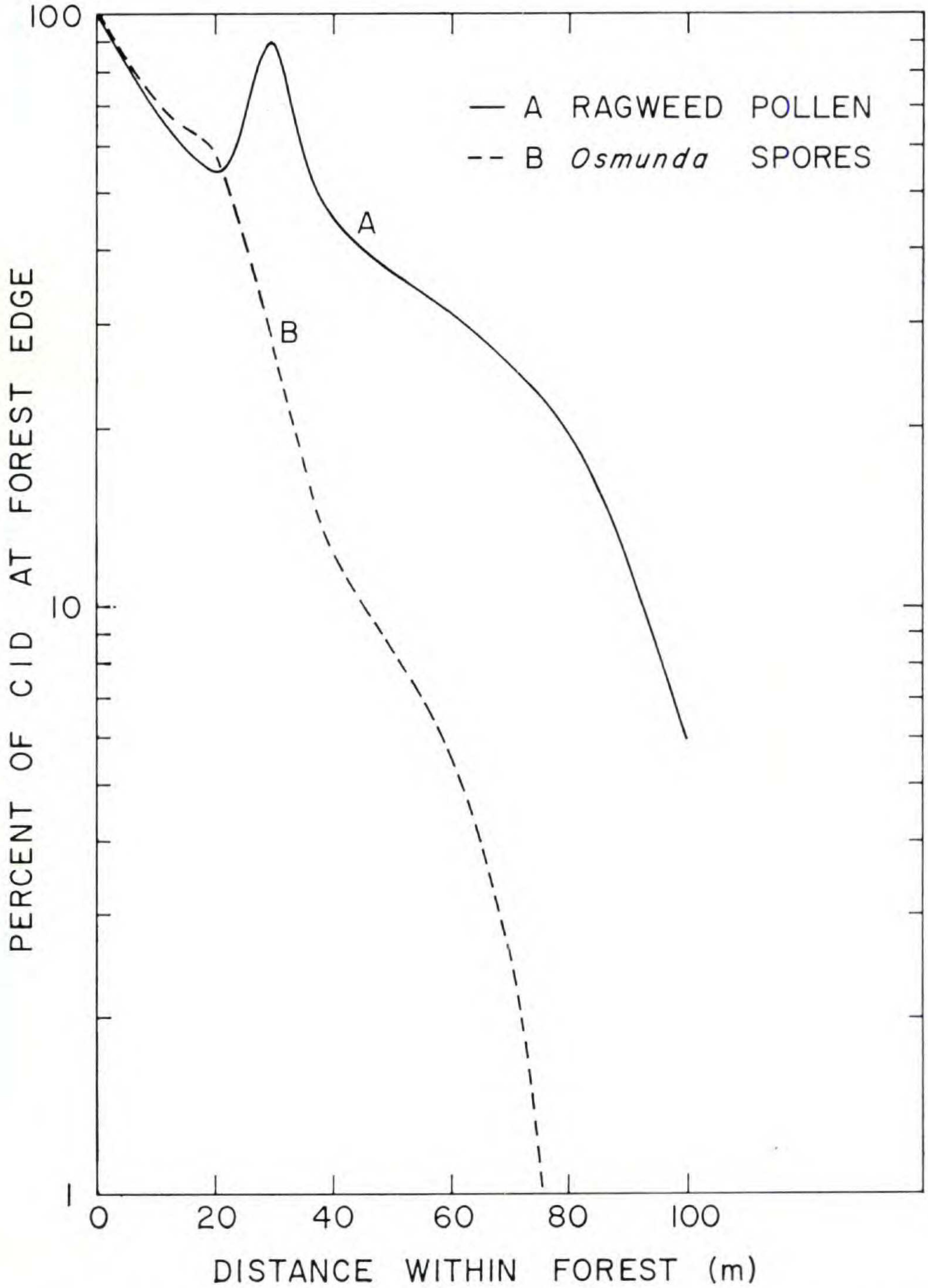

Figure 6. Normalized crosswind integrated deposition as a function of distance within the forest for simultaneous releases of ragweed pollen and *Osmunda* spores upwind of the forest edge. Test 30.

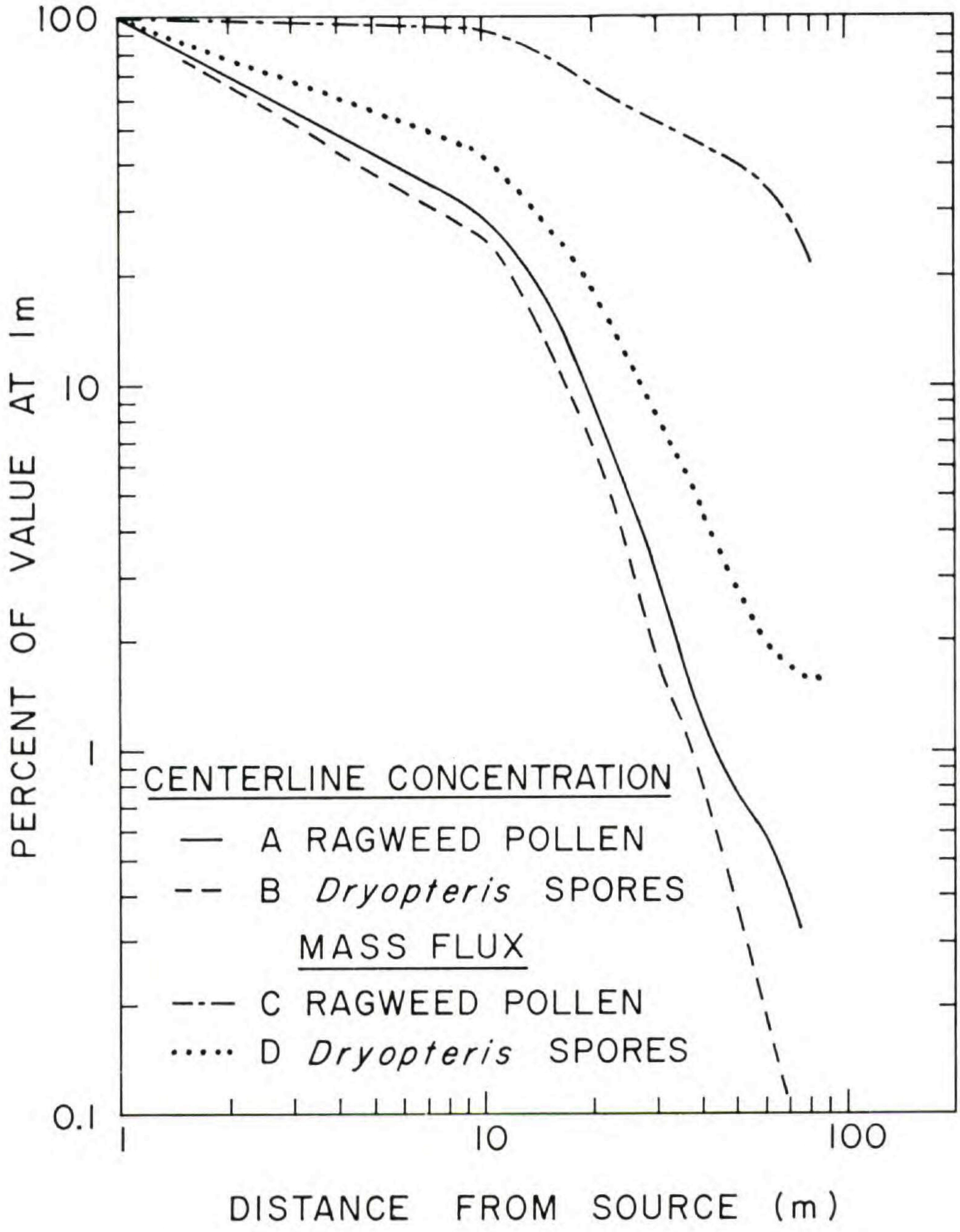

Figure 7. Normalized centerline concentrations and mass flux as a function of distance from the source for simultaneous releases of ragweed pollen and *Dryopteris* spores within the forest. Test 40.

pattern is shown instead. This is termed crosswind integrated deposition (CID). Decreases in the amounts deposited are similar for the first 20 m but much more rapid thereafter for the *Osmunda* spores.

Changes in centerline concentration and mass flux with distance from the source are shown in Figure 7 for the *Dryopteris* spores and ragweed pollen released within the forest in test 40. Centerline concentration decreased only slightly more rapidly for the spores (B) than for the pollen (A). However, the total number of grains remaining airborne was much less for the *Dryopteris* spores than for the ragweed pollen at all distances. At 80 m, more than

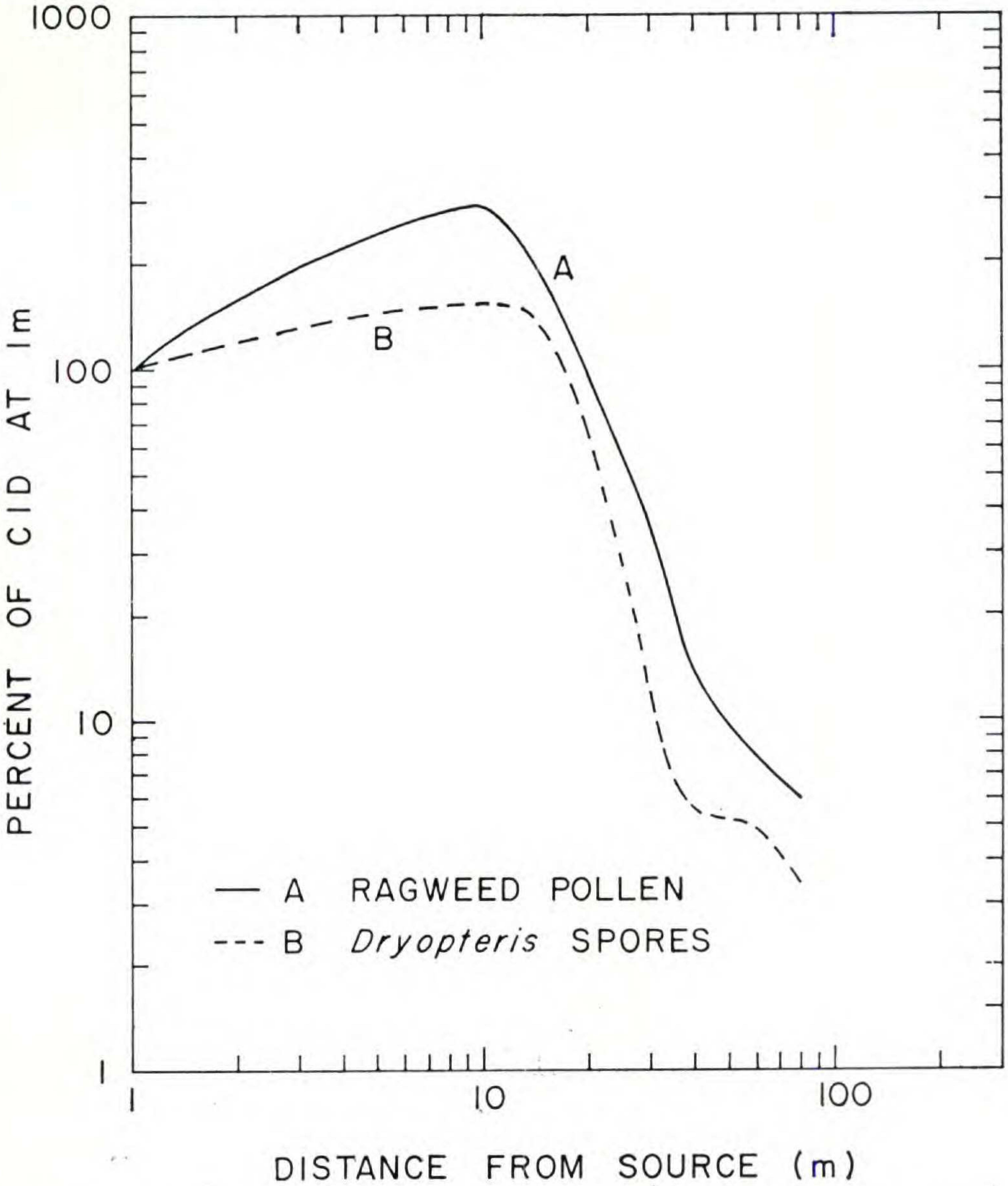

Figure 8. Normalized crosswind integrated deposition (CID) as a function of distance from the source for simultaneous releases of ragweed pollen and *Dryopteris* spores within the forest. Test 40.

10 times as many pollen grains were still airborne than fern spores.

In Figure 8, crosswind integrated deposition to the ground is illustrated for the same test. Here, differences are not as great but fern spore deposition falls off more rapidly than deposition of ragweed pollen. Peak deposition of both species is at 10-12 m from the source which is typical for a source at this height.

DISCUSSION AND CONCLUSIONS

Results indicate that fern spores of the sizes studied are dispersed by atmospheric motions in a manner qualitatively similar to smaller particles but are lost from the atmosphere faster due to their larger size and greater gravitational settling velocity. This agrees with conclusions reached from more extensive studies of particles having a wider range of sizes.

Use of quantitative measurements obtained in these tests to predict fern spore dispersion under natural conditions is difficult since vegetative, topographic and meteorological conditions will seldom be similar. However, certain generalities are evident. Spores of ferns growing in the open will be dispersed more widely and travel greater average distances than spores of ferns growing within forests. In most situations, travel distance and the length of time spores remain airborne will increase with increasing wind speed. Most spores released will settle to the ground or to other vegetation within relatively short distances, but a few may be carried long distances, particularly during periods of strong winds and good atmospheric mixing. The wide distribution of some fern species, and especially the occurrence of ferns on isolated oceanic islands (Tryon, 1970) indicate a capacity for dispersal over long distances, but probably only during exceptionally favorable circumstances. More would have to be known about the meteorological conditions under which fern spores are released naturally to attempt more quantitative predictions.

ACKNOWLEDGEMENTS

Appreciation is expressed to Dr. Rolla Tryon of Harvard University for supplying fern spores used in these experiments and for reviewing the manuscript. Numerous members of the Brookhaven Meteorology Group assisted in the experiments and in analytical procedures.

LITERATURE CITED

OGDEN, E. C., & G. S. RAYNOR. 1967. A new sampler for airborne pollen: the rotoslide. J. Allergy **40**: 1-11.

RAYNOR, G. S. 1971. Wind and temperature structure in a coniferous forest and a contiguous field. Forest Sci. **17**: 351-363.

RAYNOR, G. S., L. A. COHEN, J. V. HAYES, & E. C. OGDEN. 1966. Dyed pollen grains and spores as tracers in dispersion and deposition studies. J. Appl. Meteor. **5**: 728-729.

RAYNOR, G. S., J. V. HAYES, & E. C. OGDEN. 1972. Experimental data on particulate dispersion into and within a forest. Part I. Dispersion from upwind point sources. Informal report BNL 17750, Brookhaven National Laboratory, Upton, N. Y. 95 p.

————. 1974a. Experimental data on particulate dispersion into and within a forest. Part III. Dispersion from sources within and above the forest. Informal report BNL 19474, Brookhaven National Laboratory, Upton, New York, 48 p.

————. 1974b. Particulate dispersion into and within a forest. Boundary-layer Meteor. **7**: 429-456.

————. 1975. Particulate dispersion from sources within a forest. Boundary-layer Meteor. **9**: 257-277.

RAYNOR, G. S., & M. E. SMITH. 1964. A diffusion-deposition tracer system. Report BNL 859 (T-343), Brookhaven National Laboratory, Upton, New York, 17 p.

TRYON, R. 1970. Development and evolution of fern floras of oceanic islands. Biotropica **2**: 76-84.

GILBERT S. RAYNOR AND JANET V. HAYES
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

EUGENE C. OGDEN
NEW YORK STATE MUSEUM AND SCIENCE SERVICE
ALBANY, NEW YORK 12234